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Nursing of Patients Critically Ill With Coronavirus Disease Treated With Extracorporeal Membrane Oxygenation

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Contribution to Emergency Nursing Practice

- The current literature on the nursing care of patients on extracorporeal membrane oxygenation (ECMO) therapy in the treatment of critically ill coronavirus 2019 (COVID-19) patients indicates that severe COVID-19 is a highly contagious disease with a high case fatality rate.
- This article contributes by providing a reference and case examples to emergency nursing from intensive care colleagues in order to help improve the treatment and effective nursing care of critically ill patients with COVID-19 on ECMO.
- Key implications for emergency nursing practice found in this article are case examples to reinforce strict prevention, timely observation, effective management of complications, and efficient ECMO procedures as key ways to successfully treat critically ill COVID-19 patients.

Introduction

Since the end of 2019, coronavirus disease (COVID-19) has spread rapidly from Wuhan to other parts of China.[1,2] Approximately 17% of the patients with this disease became critically ill and had symptoms such as acute respiratory distress syndrome (ARDS), respiratory failure, and multiple organ dysfunction syndrome, which may ultimately lead to death.[1] Medical experts in different fields have stated that it is difficult to treat severe or critically ill COVID-19 cases.[2,3,4]

Xinyang, in Henan province, a city close to Wuhan, took in 110,000 home returnees from Wuhan and was severely afflicted by the disease. Up until midnight on February 24, 2020, 274 COVID-19 cases were confirmed in Xinyang. Among them, 6 patients who were critically ill were hospitalized in the intensive care unit (ICU) of the Fifth People's Hospital of Xinyang and were managed by the critical care medicine team from our hospital. Three of the patients underwent pulmonary re-expansion and optimization of mechanical ventilation after endotracheal intubation (fraction of inspired oxygen [FiO_2] 1.0; tidal volume 4-6 ml/kg; and positive end-expiratory pressure [PEEP] $\geq$10 cmH_2O); however, their oxygenation indexes remained below 80 mmHg for more than 6 hours. Extracorporeal membrane oxygenation (ECMO) was used after confirming that the patients had no contraindications to the therapy.

ECMO is an effective technique that provides cardiac and respiratory support. This form of treatment can provide temporary cardiac and respiratory support for patients who are critically ill by oxygenating their blood and allowing the lungs to rest, giving medical staff the time to treat the primary disease and repair the lungs. According to the Extracorporeal Life Support Organization, in January 2015 the survival rate of patients with viral pneumonia on ECMO was 65%.[5]

Among the 3 patients who received ECMO therapy, 2 patients recovered, and ECMO was discontinued successfully, whereas 1 patient died. The clinical data, clinical characteristics, treatment, and nursing experience of the 3 patients who were critically ill with COVID-19 and were on ECMO were reported in this manuscript.

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Clinical Data

GENERAL DATA

Three patients critically ill with COVID-19, who were confirmed to have the disease through nucleic acid tests from throat swabs and who were on ECMO in the ICU of the Fifth People's Hospital of Xinyang from February 2, 2020, to February 24, 2020, were enrolled in the present study. Each patient satisfied the diagnostic criteria found in the Diagnosis Criteria of Coronavirus Disease 2019 (Trial, Fourth Version) released by the National Health Commission of the People's Republic of China in February 2020.[6] Among them were 2 male patients—1 aged 54 years and the other aged 62 years—and 1 female patient aged 61 years. The 54-year-old male patient had diabetes, and the 62-year-old male patient had hypertension. The female patient, however, had no underlying diseases. Each of the 3 patients weighed between 60 kg and 75 kg and had a travel history within the epidemic area.

Methods

The patients were treated in accordance with the Diagnosis and Treatment Scheme of Coronavirus Disease 2019 (Trial, Fourth Version), which was released by the National Health Commission of the People's Republic of China in January 2020.

GENERAL THERAPY

Currently, no specific therapy exists for treatment of COVID-19. It is generally suggested that patients should have bed rest; consume nutritious food; receive immune supportive therapy; take in sufficient calories; maintain water, electrolyte, and acid-base balance; and receive effective oxygen therapy. All 3 patients were given antiviral therapy. Human immunoglobulin, human albumin, and thymalfasin were used to strengthen the immune system, and methylprednisolone was administered to inhibit excessive inflammatory reactions, whereas biapenem was combined with moxifloxacin for anti-infective therapy. Moreover, the patients were administered lipid emulsion, amino acids, and glucose in terms of nutritional support.

SPECIAL THERAPY

All 3 patients underwent invasive mechanical ventilation through oral endotracheal intubation for respiratory support as well as right femoral vein cannulation through percutaneous puncture for blood drainage. The centrifugal pump delivered the blood to the ECMO device to carry out the exchange of oxygen and carbon dioxide. The temperature of the blood was maintained at 36°C to 37°C (96.8°F to 98.6°F) by temperature regulation of the water tank; the blood then entered the right jugular vein and reached the venovenous-ECMO supportive treatment in the right atrium. The ECMO device and disposable medical products were produced by Sorin Group (Figure 1).

Results

The abnormal laboratory indexes of the patients with COVID-19 are shown in the Table. According to previous investigations, differences in lymphocytes, lactic dehydrogenase, D-dimer, and N-terminal pro b-type natriuretic peptide were found to be statistically significant between ordinary patients with COVID-19 and those who were critically ill with COVID-19. In the present study, even among the group who were critically ill and on ECMO, the patient who died had indexes further out of the normal range than the patients who survived.

NURSING

Follow Strict Prevention Measures to Ensure the Safety of Clinical Staff

People are susceptible to COVID-19. It is currently known to spread mainly through close contact between individuals and through small droplets.[6] The blood, bodily fluids, and secreta of patients with COVID-19 are highly infectious. The body and skin of clinical staff are exposed to potential splashes of secreta, blood, bodily fluids, or contaminants, especially in the high-speed airflow generated from the ventilator and the ECMO machine, putting them at high risk. Clinical staff should take strict precautions against air, droplets, and contact that may cause infection. According to the Guidelines for Prevention and Control of Novel Coronavirus Infection in Medical Institutes (First Version) released by the National Health Commission,[7] clinical staff

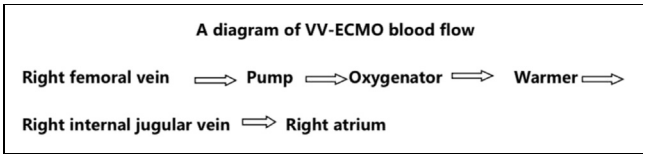

FIGURE 1

Diagram showing VV-ECMO blood flow. VV-ECMO, venovenous extracorporeal membrane oxygenation.

TABLE
Clinical characteristics of 3 patients critically ill with COVID-19 treated with extracorporeal membrane oxygenation

Clinical characteristic	54-year-old male patient	62-year-old male patient	61-year-old female patient
From onset to dyspnea (d)	17	4	3
From invasive mechanical ventilation to use of ECMO (h)	15.5	31	39
Duration of ECMO support (h)	118	89	216
Minimum value of lymphocytes (normal range 1.1-3.2 $\times$ 10^9/L)	0.19	0.24	0.18
Maximum value of lactic dehydrogenase (normal range 135-255 U/L)	562	535	1993
Maximum value of D-dimer (normal range 0-0.5 mg/L)	23.13	8.46	5.4
Maximum value of NT-proBNP (normal range 0-100 pg/mL)	722.7	4661.02	8150.74
Prognosis	ECMO discontinued	ECMO discontinued	Died

COVID-19, coronavirus disease; ECMO, extracorporeal membrane oxygenation; NT-proBNP, N-terminal pro b-type natriuretic peptide.

should wear 12 items of personal protective equipment (PPE), including fission-type work clothes; disposable medical hoods; disposable surgical masks (or KN95 or N95 masks); coveralls; goggles; face shields or full respiratory protective devices or positive-pressure hoods; disposable fluid-resistant shoe covers; rubber boots; isolation gowns; disposable surgical masks; and 2 pairs of latex gloves. Staff should stand in front of a mirror strictly following the wearing and doffing sequence as described in a poster on the wall to ensure that the protective equipment is worn correctly. After duty hours, the protective equipment should be removed in a top-to-bottom and outside-to-inside sequence. Hand hygiene should be strictly practiced each time a piece of equipment is removed. Finally, the staff should take a bath, put on clean clothes, leave the isolation area, and return to the resting room. It is important to ensure the safety of clinical staff. During the course of the treatment, no members of the clinical staff were infected.

ECMO MANAGEMENT

ECMO Initiation

Once the clinical staff donned their PPE, their field of vision was restricted, and it was not easy for them to move freely. Wearing 2 pairs of gloves makes it difficult to feel certain objects, and a minimum number of clinical staff were allowed in the isolation wards at any specific time. Therefore, it is important to fully prepare the staff and the PPE gear before ECMO initiation. The ECMO initiation checklist was prepared in advance, and every staff member present played a role. In the ECMO team, 1 associate senior physician decided the treatment scheme of the patients, and 2 attending physicians helped the associate senior physician in cannulation and disease management. Moreover, 1 professional ICU nurse took care of the patients, whereas 1 professional ECMO nurse prepared the ECMO device and circuits. In addition, 1 radiologist performed X-rays of the patients' chests. ECMO is typically initiated by an associate senior physician in the ICU.

Assessment and Obtaining Consent

Cardiopulmonary function and vessels were assessed by the associate senior physician in the ICU who confirmed the mode of ECMO therapy and created an ECMO supportive scheme. The physician in charge explained the ECMO therapy to the patients and their family members, who then signed an informed consent. Patients without family members were authorized by the department in charge.

ECMO Preparation

All items needed for the ECMO therapy were prepared. Specifically, ECMO nurses prepared all items following a list of instructions and prepared the bedside ultrasonic apparatus. The bilateral skin preparation range for the femoral venous puncture was taken from the navel to the knees, whereas that for the internal jugular vein puncture was taken from the lower lip to the nipples. The catheter was connected, and the power supply, gas supply, and water

tank were checked to ensure that the electric and gas circuits were correctly connected.

ECMO Priming

The ECMO circuits were primed with 3 L of 0.9% sodium chloride solution, and the air in the circuits, membrane lung, and centrifugal pump head was exhausted by controlling the priming solution with clamps to ensure that no air was present in the system. Afterward, the ECMO centrifugal pump head, oxygenator in the centrifugal pump, and ECMO transfer trolley were fixed for further use. Before the ECMO cannulation, the patients underwent deep sedation and analgesia given by the nurses, with a Richmond Agitation-Sedation Scale score of –4 to 5 points and Critical-Care Pain Observation Tool score of 0 points to prevent restlessness caused by pain that may lead to blood spatter and transmission of aerosols.

Cannulation

With the help of the other 2 physicians, the patient adopted the supine position without a pillow, which was followed by routine sterilization and draping. The femoral and jugular veins were cannulated through the skin, and the cannulas were then fixed. After the initial successful establishment of vascular access, the patients were given 3,000 U heparin intravenously while the nurse monitored the patients' vital signs as well as the equipment. After cannulation, the venous cannula was connected correctly; the ECMO device was started; the flow was adjusted; and the cannula and various catheters were fixed to avoid traction, bending, or falling off to ensure that the machine ran normally. In addition, 50 mL 250 U/mL heparin saline was prepared, and the intravenous dose was adjusted according to the bedside activated clotting time results, which were kept within 180 seconds to 200 seconds.

Waste Disposal

All waste was placed in a yellow double poly bag, sealed using the goose-neck method, and labeled "novel coronavirus," which was then placed at a designated location. All waste was dealt with by a specially assigned person (Figure 2).

Management of ECMO

During the initial stage of ECMO, the oxygen debt was paid back as soon as possible at high flow, and the speed was controlled at 50 mL/kg/min to 70 mL/kg/min. The flow may be decreased according to the patient's cardiopulmonary function after improvement in oxyhemoglobin saturation and once hemodynamics are stable. The changes in hemodynamics were monitored closely: temperature, heart rate, blood pressure, oxyhemoglobin saturation, central venous pressure, and invasive arterial blood pressure were monitored. The temperature of the water tank was adjusted in accordance with the patient's temperature, and the pump speed and flow were adjusted according to a blood gas assay. Blood gas assay, electrolytes, blood routine, and bleeding and coagulation indexes as well as the functions of the heart, liver, and kidneys were monitored. The flow and speed were checked to determine whether they matched; if they did not, an alarm would be triggered. The presence of thrombi in the circuits and membrane lung was also checked.

Sedation and Analgesia

The patients underwent deep sedation and analgesia with a Richmond Agitation-Sedation Scale score of −4 points and Critical-Care Pain Observation Tool score of 0 points.

Bleeding and Coagulation

Bleeding and coagulation were monitored every 2 hours in the initial stage, after which coagulation was monitored every 4 hours. The dose of heparin was adjusted according to the results of the activated partial thromboplastin time and D-dimer, and the activated partial thromboplastin time was kept within 50 seconds to 60 seconds. Arterial blood gas analysis was carried out every 4 hours to 8 hours, and ECMO gas and blood flow were adjusted according to the partial pressure of carbon dioxide and oxyhemoglobin saturation. The partial pressure of carbon dioxide was maintained at 40 mmHg, whereas that of oxyhemoglobin was 95%. Chest x-rays were performed every 1 to 2 days to observe changes in pulmonary imaging.

Ventilator Parameters

Low tidal volume (<4 mL/kg weight), low pressure (target flat pressure <25 cmH_2O; PEEP <15 cmH_2O), lung protective ventilation strategy, and pressure-synchronized intermittent mandatory ventilation mode were adopted.

Blood Lactic Acid

Blood lactic acid was controlled at below 3 mmol/L, and attempts were made to keep the patients at a negative fluid balance, reduced pulmonary exudate, and improved level

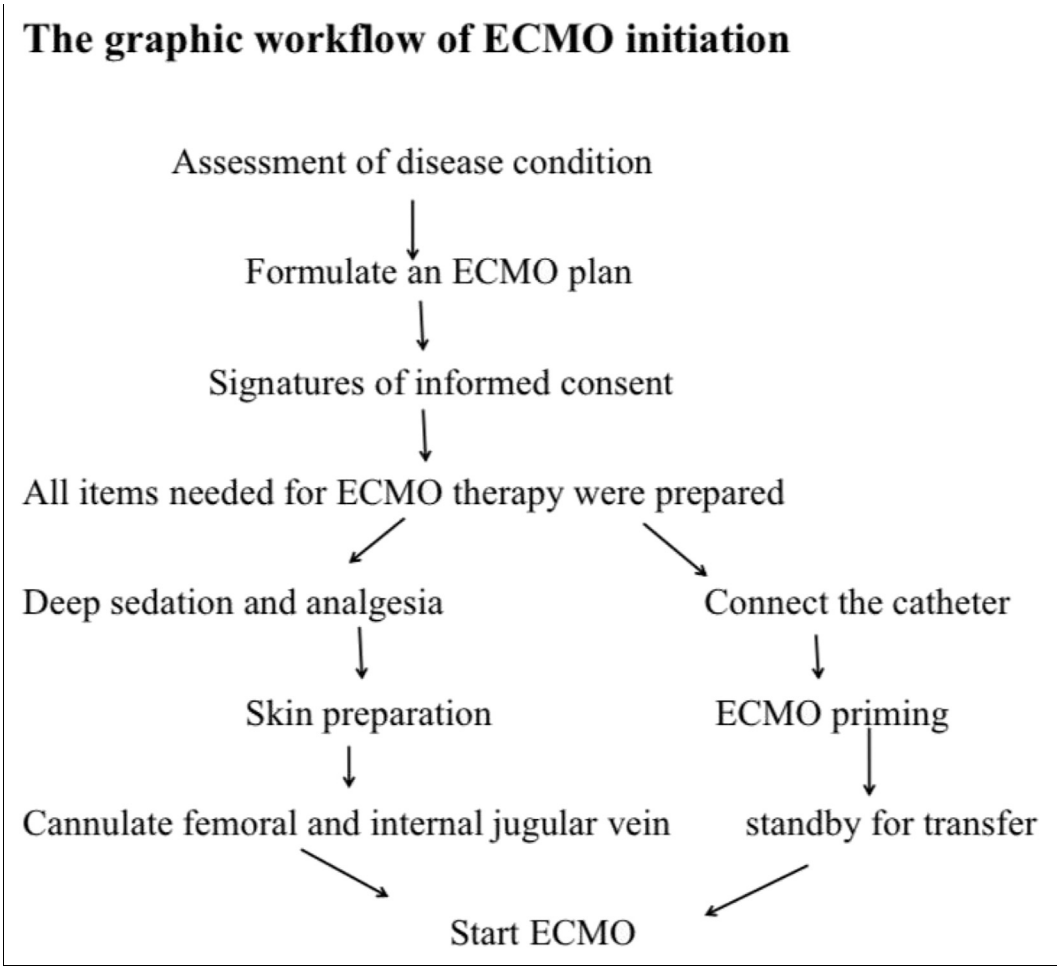

FIGURE 2
ECMO initiation workflow. ECMO, extracorporeal membrane oxygenation.

of oxygenation. Ventilator-associated pneumonia and catheter-associated bloodstream infection were prevented and controlled. The patients were turned over to prevent pressure ulcers.

Clinical Staff Management

The nurses adhered strictly to the shift system: owing to the infectiousness of such diseases, the clinical staff wore protection products when entering the isolation area and could not drink water or go to the toilet. As frequent shifts may increase the risk of adverse events, the clinical staff changed shifts every 4 hours, checking the patients' conditions in accordance with the ECMO nurses' checklist for patients with COVID-19 before each shift. They notified the physician if any abnormal conditions were observed. Furthermore, they ensured that the ECMO process ran smoothly.

OBSERVATION AND PREVENTION OF ECMO COMPLICATIONS

Bleeding

Bleeding is the most common and severe ECMO complication. According to the Extracorporeal Life Support Organization, the incidence of bleeding is 22.2% when ECMO is used for respiratory support.[5] During ECMO, systemic heparinization, blood cell damage, damage to coagulation mechanisms, and vascular injury are the main factors that result in bleeding. To prevent bleeding, the cannula was properly fixed, the wound was observed, and coagulation indicators were monitored periodically. Abnormal events were reported to the physicians. Existing venous channels were maintained, and new venous conduits were not inserted. Intramuscular and subcutaneous injections were reduced,

mucosal injury was avoided during sputum suction, and insertion of nasal feeding tubes and oral care were performed. Bilateral pneumothorax and hemothorax occurred in the 61-year-old female patient after 26 hours of ECMO. Massive hemorrhage and hemorrhagic shock occurred after thoracic close drainage. Heparin was stopped, and the patient was transfused with packed red cells, but the patient still died owing to multiple organ failure. Pneumothorax may have been caused by excessive PEEP (14 cmH_2O to 16 cmH_2O), although bleeding did not occur in the 2 male patients.

Hemolysis

Hemolysis is a type of mechanical damage in red blood cells caused by ECMO. The urine color and presence of jaundice should be closely observed. The speed and flow should be adjusted according to the patients' conditions. If hemolysis was caused by a thinner cannula, then the cannula was changed. To prevent renal impairment caused by hemolysis, the alkalization of urine, diuresis, and continuous renal replacement therapy were performed if deemed necessary. Hemolysis did not occur in the 3 patients.

Infection

Patients with COVID-19 may develop severe secondary infection or even septic pyemia while on ECMO. The possible causes include infection at the cannulation site, catheter-associated bloodstream infection, invasive mechanical ventilation, and other infections caused by the cannula and other components.

Prevention and treatment. Strict aseptic techniques were followed during ECMO initiation and management. It is important to avoid collecting blood from the ECMO circuit and avoid the use of unnecessary invasive equipment and operations to prevent ventilator-associated pneumonia.

Mechanical Complications

Complications caused by the ECMO device and components include plasma leakage or thrombus owing to failure of the centrifugal pump head or oxygenator, gas embolism, cannula displacement or slippage, and power/air supply failure.

Prevention and treatment. The patients were observed closely to ensure the normal execution of ECMO. Oxygenator thrombosis may cause gas exchange failure, which is related to the underuse of anticoagulant therapy and slow blood flow rate. This requires adjusting the anticoagulant level and ECMO flow as well as monitoring the transmembrane pressure. The oxygenator was checked periodically and changed if it did not function well. Mechanical complications did not occur in the 3 patients.

MANAGEMENT OF ECMO WEANING

After confirming stable hemodynamics—evident improvement in lung imaging, gradual decrease in the oxygen concentration of the membrane oxygenator, and restoration of the pulmonary function—the staff gradually reduced and observed the oxygen flow of the membrane oxygenator, evaluated the patients' lung function, and increased the ventilator FiO_2 to 100%, observing the partial pressure of oxygen to note if it increased rapidly as the FiO_2 increased. The patients' lung function was reassessed and deemed adequate to proceed. Afterward, the physician assessed the patients' lung function and upregulated the ventilator to an acceptable condition. If the transcutaneous oxygen saturation reached 95% for 12 hours or more while the oxygenation index in the blood gas assay was more than 200 mmHg, then ECMO support could be withdrawn.

Weaning Process

The ECMO device was powered off, and the internal cannulas of the right femoral vein and right internal jugular vein were clamped and removed. Pressure was held on the cannulation sites for 1 hour, which was followed by pressure dressing kept on for 24 hours. The extracorporeal circulation tubing was removed, and the device, which had been powered off, was checked and the record maintained according to the user guide.

Discussion

At present, no specific treatment exists for COVID-19, and patients who are critically ill with COVID-19 can rapidly develop ARDS, respiratory failure, and multiple organ dysfunction syndrome,[1] leading to death. ECMO, a cardiopulmonary bypass technique able to replace or augment the function of the lungs and heart, has been applied in an increasing number of patients who are critically ill and suffering from respiratory failure and/or circulation failure in the past 10 years.[8,9] When venovenous-ECMO was applied for ARDS, it was found to perform extracorporeal gas exchange and allow the lungs to fully rest, giving time for the recovery of the pulmonary function so that the patients may recover.[7]

In the present study, the 3 patients who were critically ill with COVID-19 had "white lung," and their lungs had lost the function of gas exchange. Hypoxia was not relieved even when the ventilator was used; hence, ECMO therapy was used in the 3 patients. Among them, 2 cases were successful—the patients' lives were saved—but 1 patient died owing to complications. From the death of this 1 patient, we concluded that during ECMO operation, the pressure level of ventilator support should be low—PEEP of 14 cmH_2O or less—and invasive operations should be avoided to prevent bleeding; indeed, the prevention of complications is the key to successful treatment. The blood, bodily fluids, and secreta of patients with COVID-19 are highly infectious. Consequently, the clinical staff wore different PPE sets during nursing and treatment, impeding their sense of vision, hearing, feeling, and sensitivity significantly, making the treatment and nursing of such patients more difficult. Before ECMO initiation, all articles should be well prepared, and the clinical staff should don PPE in the correct sequence. All procedures should be performed in a slow, steady, and accurate manner, and the clinical staff should cooperate closely with each other to ensure a smooth ECMO initiation. During the running process, the clinical staff usually changed shifts every 4 hours, decreasing the risk of adverse events in nursing. All clinical staff strictly followed the shift system and checked the patients' conditions every 2 hours in accordance with the ECMO nurses' checklist for patients with COVID-19. The corresponding results were recorded, which prevented complications and ensured a smooth ECMO process. Hemostasis should be established properly at the puncture site during weaning. Accordingly, ECMO was shown to have successfully saved the lives of 2 patients who were critically ill with COVID-19. And no member of the medical staff was infected during the entire treatment process (Supplementary Table).

Author Disclosures

Conflicts of interest: none to report.

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Supplementary Data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jen.2020.07.006.

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Supplementary Data

SUPPLEMENTARY TABLE

Checklist of extracorporeal membrane oxygenation (ECMO) nursing for patients with COVID-19

Bed No.:

Name:

Inpatient No.:

Catheters duration Mode:

Doctor in charge:

Items	Time of evaluation
	The time at shift change/Moving the patient
Vascular cannula site	Whether it is sutured
	Whether there is active bleeding or errhysis
	Whether there is sludged blood in the tube
	Whether the cannula is fixed
	Whether the cannula is moved (mark in the spot)
Centrifugal pump	Whether the emergent hand crank is placed in the correct location
	Whether there is thrombus or air in the centrifuge pump
	Whether there is abnormal sound in the centrifuge pump
	Whether the coupling agent should be changed
ECMO machine	Whether the power supply is well connected
	Whether there is UPS power supply
	Whether the display screen is normal
	24 h flow back to normal
Oxygenator	Whether the air flow matches the blood flow
	Whether the gas outlet is open
	Whether there is water drop or plasma in the gas outlet
	High-flow gas membrane lung (PRN)
	Whether there is bubble in the head of the oxygenator
	Fore and aft pressure difference
	Whether there is thrombus (detail it if there is any)
Oxygen/air blender	Whether the oxygen supply is well connected
	Whether the air supply is well connected
	Oxygen concentration/air flow
	Whether there is abnormal sound
Water tank	Whether the power supply is well connected
	Whether the water tank is well connected
	Whether the set water temperature is consistent with the actual water temperature
	Whether the water line is up to standard
Vascular cannula site	Whether it is sutured
	Whether there is active bleeding or errhysis
	Whether there is sludged blood in the tube
	Whether the cannula is fixed
	Whether the cannula is moved (mark in the spot)

continued

SUPPLEMENTARY TABLE
Continued

Items	**Time of evaluation**
	The time at shift change/Moving the patient
Blood circulation in the lower limbs	Arteriopalmus of dorsum pedis
	Whether ischemia, stiffness or cyanosis occurs in the lower limbs
Other observation indexes	Urine color
	Color and nature of drainage fluid
	Consciousness
	Circumference of limbs
	Wiping the device
	Axial rolling over and no folding or bending in the circulation loop
	Skin disinfection (chlorhexidine)
	Dose of anticoagulant drugs (U/H) maximum/minimum
Management of targets	ACT range
	Hemoglobin
	APTT
	Blood glucose
	Heart rate
	Blood pressure
	Oxygen partial pressure
	Oxygen saturation
	Capacity management
Emergency medical tools	Four hemostatic forceps
	Hand crank
Signature of checker	

Note: Please check the above items closely and mark "√" for "Yes" and "×" for "No."
COVID-19, coronavirus disease; ECMO, extracorporeal membrane oxygenation; PRN, pro re nata; UH, unfractionated heparin; ACT, activated clotting time; APTT, activated partial thromboplastin time.